

An insight into subwoofers

The fast spread of discrete multichannel audio logically reinforces the use and development of subwoofer speakers. While subwoofers are extensively used in professional, consumer, home theatre, car audio and movie theatre markets, the history and development of their design and technology is quite poorly documented.

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IN THE MID-1950S various manufacturers of hi-fi speakers started to introduce fairly compact sealed cabinet enclosures that had long-throw type woofers. In the early 1970s Jensen had a talented engineer, James Novak, who came up with equations describing a bass reflex speaker design. Other researchers, such as Thiele, Small, Ashley and Benson, continued with Novak's ideas and refined the mathematical analysis and synthesis for closed, vented and passive radiator speaker systems. Since then, several software packages have evolved to make the system design even easier.

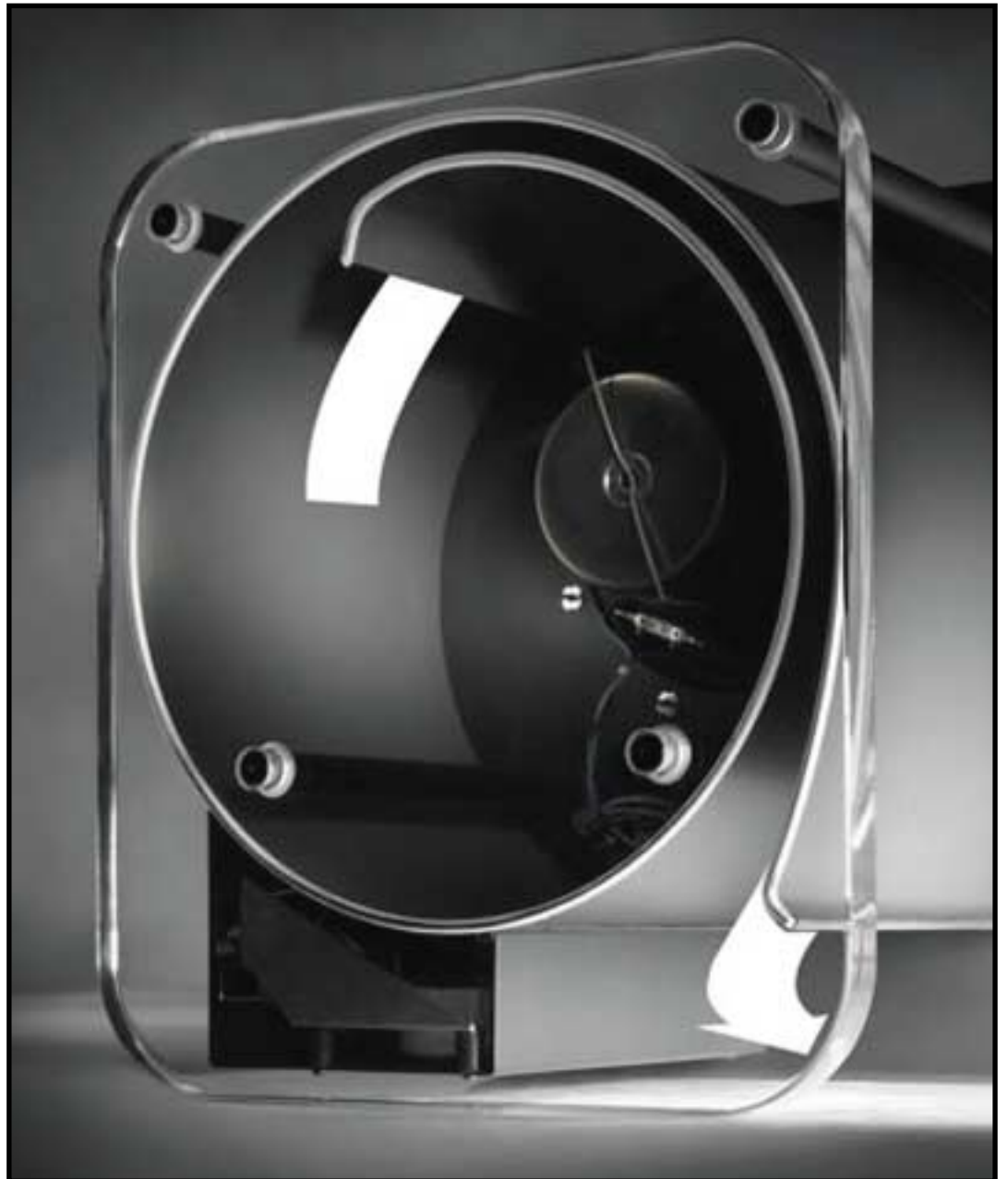
The ability to reproduce extended low frequencies was of great interest to the movie industry. In the 1950s Cinerama – then Cinema-scope – and Todd-AO Studios first brought multichannel sound to the large cinema screen. A 6-track 70mm Todd-AO system premiered in 1955 and in 1976 an adaptation of this system was developed that featured a centre mono channel with dialogue mixes only, leaving the left and right channels with a new role as 'bass extension' channels. These two channels provided low frequency effects made to enhance the cinema experience. The first movie to feature this 'bass extension' was Star Wars in 1977.

In 1992 Dolby Digital was introduced with the cinema release of Batman Returns, which made a very clear step forward in the use of the LFE or '.1' channel in audio, video and movie productions.

If subwoofers had become an important addition to standard stereophonic reproduction systems during the late 1970s, today, with the wide acceptance of multichannel audio, they have become an essential device in any type of reproduction system, whatever its cost and size might be. In most cases, the subwoofer reproduces a significant bandwidth of the LFE channel, and also the very low frequencies of some or all main channels, with the help of a bass management system.

There are a few facts about low frequency reproduction and hearing that have to be considered. The location of a subwoofer with respect to room walls will strongly affect how the subwoofer excites the low frequency acoustics of the room. Also, relative to a free field acoustical space, once a subwoofer is placed on a floor and against a wall, there is a 12dB level increase (this amplitude gain of 6dB per wall occurs usually below a few hundred Hz, where the radiation is fully omnidirectional), and once it is placed in a corner, the increase is 18dB. This change in the available sound pressure, due to power doubling at each halving the radiation space, is beneficial to subwoofer design as it enables reproduction of low frequencies with less distortion.

At low frequencies the room absorption is usually less effective and because the room modes are sparsely located, the separate standing waves are easily audible. A measurement of a subwoofer in a certain position will reveal the performance of the subwoofer in that location only. When the position changes, so will the acoustics of the room, and hence the



subwoofer performance might suddenly be very different from the initial position. The variations in room acoustic behaviour create large variations in frequency response, which strongly colour the perceived bass quality.

At very low frequencies the auditory sensation of sound changes and the pitch recognition disappears and becomes a feeling of pressure. Researchers Guttman and Pruzansky [1] initially established that this change occurs at about 19Hz. Further research by Buck [2] showed that the average lower limit of pitch was perceived at 12Hz with 120dB SPL of pure tone

signals. The ability to hear pitch changes depends on SPL (9.6Hz at 123dB, 7Hz at 129dB). These results are in direct relation to the work of Fletcher and Munson[3] in 1933, and Robinson and Dadson[4] in 1956 (see Figure 1) about the minimum threshold of hearing. It shows clearly that our hearing is not very sensitive to low frequencies reproduced at low level. As the level increases the audibility improves, but is far weaker than in the midrange band. It also shows that, to generate any audible sound, the subwoofer has to have a certain minimum output capability.

The most essential property and requirement for a

subwoofer is its capacity to move air. In the final technical specification this converts to the maximum driver excursion and effective piston area.

To achieve a constant sound pressure level while decreasing frequency, the necessary air volume displacement is proportional to $1/(\text{frequency})^2$. In other words, the air volume displacement increases by 12dB per octave with decreasing frequency. This relationship does not depend on the type of enclosures used. So, if we need for example 50cm³ of volume displacement at 100Hz for 110dB SPL, we need 1250cm³ at 20Hz for the same SPL. Additionally each doubling of the SPL (+6dB) needs twice the volume displacement. Hence the constraints on the driver excursion and diaphragm, as well as on its suspension, are significant when you want to achieve high sound pressure level as well as low frequency extension.

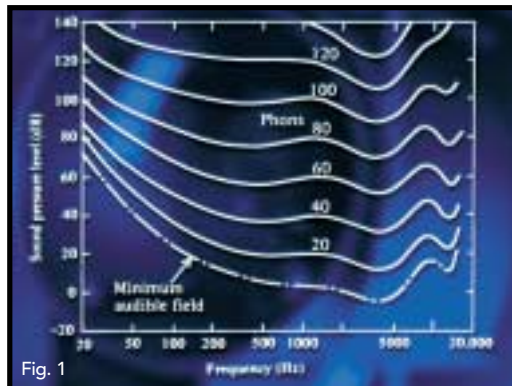
Most subwoofers are built around closed, vented, band-pass or transmission line box principles. The most common of these are closed and vented boxes. Again, independent of the type, the efficiency is proportional to the size of the box. The smaller the box, the lower the efficiency and consequently, the higher the necessary amplifier power for a certain SPL output. Hence, you can see very small enclosures with 1000W amplifiers with, in fact, a final SPL output identical to the output of a larger box with a 100W amplifier.

Comparison of the performance of a closed box and a vented box of the same internal volume will reveal a number of things. The efficiency of a closed box is lower than that of a vented box and to get the same efficiency the low frequency cut-off of a closed box will be higher. The driver displacement capacity must be higher in a closed box and, due to the required longer excursion of the driver in a closed box, the distortion is in practice often higher. Finally, the impulse response of a closed box is often better than that of a vented box.

There are constraints in vented subwoofer design. Because of the performance benefits, since the late 1970s many manufacturers have developed 'vented' or 'reflex' enclosures. The vent – or reflex port – is an integral and necessary part of the design and research to improve the vent performance and efficiency has been pursued over the years.

Looking at the acoustical phenomena and their mechanical analogies for a reflex enclosure, the vent and the box form a 'mass-spring' resonant circuit. The 'spring' is the air inside the box and the 'mass' is the acoustical mass of the air in the vent. This acoustical mass is proportional to the ratio of the vent length to its cross sectional area. The same acoustical mass can be achieved with very different dimensions; a small vent area with a short tube is equivalent to a large vent area with a long tube. However, not any combination is valid.

At the vent-enclosure resonant frequency most of the radiation comes out of the vent. If we have 110dB SPL coming from the driver, the same is coming from the vent but at a lower frequency. This implies that there is a lot of air movement in and out of the enclosure through the vent. Because of that, the next step is to look at the air flow properties inside the vent. To minimise the speed of the air flow the cross sectional area of the vent should be large. As a consequence (to keep the correct acoustical mass) the vent becomes



long. When the vent length grows, the enclosure dimensions soon start limiting the maximum length that will fit inside a normal enclosure.

In conventional designs, the vent is sometimes bent to gain additional length in the speaker enclosure but acute angles in the vent shape will cause increased air turbulence. Air turbulence means losses that increase rapidly with sound pressure level and cause audible noise, compression and distortion.

One elegant solution to this problem was published by Harry F. Olson. He substituted a long vent with a 'drone cone', a heavy speaker cone without voice coil and magnet (hence it is called a passive radiator). The acoustical mass of the passive driver diaphragm is made equal to the acoustical mass of the column of air in a theoretical long vent, and in general, the system performance is equivalent to a vented enclosure.

Passive radiators do not take much space in the enclosure, but without proper design their performance can limit the maximum system output. Above a certain sound pressure their displacement becomes non-linear and the dynamic range is limited. Naturally this should not happen before the driver starts reaching its limits. Therefore the passive radiator is

often larger than the driver is, or there will be several passive radiators for one active driver.

Coming back to the vented design, there are two main problems in the vent: its possible length and turbulence. To avoid turbulence in the vent, the air flow should be laminar. To keep this flow laminar, the vent shape must be smooth without sharp angles, the air speed in the tube must be low enough and the vent ends have to be acoustically properly terminated.

To design a subwoofer that incorporates all the above crucial acoustical parameters, Genelec developed the LSETM series subwoofers. The enclosure shape is made from a strip of sheet metal that is wrapped to a spiral. The vent is formed between the rounds of the spiral. The length of the tube can be as long as needed, matching the SPL output and the air flow required. The vent is located at the perimeter of the enclosure and has no acute angles. The radius of the spiral being variable, the vent height also changes along the tube length avoiding any tube whistling and chuffing. The vent ends are also carefully formed to provide a proper termination and a smooth flow transition between the various air volumes – inside the enclosure, in the vent and in the room.

The minimised losses in the reflex tube and its smooth shape provide clarity and definition with low distortion. So, despite a fairly small enclosure size, you can achieve very low frequency reproduction at high level. ■

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